The Effect of Testosterone Replacement on Endogenous Inflammatory Cytokines and Lipid Profiles in Hypogonadal Men

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Testosterone has immune-modulating properties, and current in vitro evidence suggests that testosterone may suppress the expression of the proinflammatory cytokines TNFα, IL-1β, and IL-6 and potentiate the expression of the antiinflammatory cytokine IL-10. We report a randomized, single-blind, placebo-controlled, crossover study of testosterone replacement in 27 men (age, 62 ± 9 yr) with symptomatic androgen deficiency (total testosterone, 4.4 mmol/liter; bioavailable testosterone, 2.4 mmol/liter; placebo-controlled). Compared with placebo, testosterone induced reductions in TNFα (−3.1 ± 8.3 vs. 1.3 ± 5.2 pg/ml; P = 0.01) and IL-1β (−0.14 ± 0.32 vs. 0.18 ± 0.55 pg/ml; P = 0.08) and an increase in IL-10 (0.33 ± 1.8 vs. −1.1 ± 3.0 pg/ml; P = 0.01); the reductions of TNFα and IL-1β were positively correlated (rS = 0.588; P = 0.003). In addition, a significant reduction in total cholesterol was recorded with testosterone therapy (−0.25 ± 0.4 vs. −0.004 ± 0.4 mmol/liter; P = 0.04). In conclusion, testosterone replacement shifts the cytokine balance to a state of reduced inflammation and lowers total cholesterol. Twenty of these men had established coronary disease, and because total cholesterol is a cardiovascular risk factor, and proinflammatory cytokines mediate the development and complications associated with atheromatous plaque, these properties may have particular relevance in men with overt vascular disease. (J Clin Endocrinol Metab 89: 3313–3318, 2004)

TESTOSTERONE IS THE predominant androgenic hormone and has a range of biological actions. The classical effects of testosterone are the induction and maintenance of secondary sexual characteristics and preservation of libido, sense of well-being, lean mass, and bone density. The hormone is involved in a negative biofeedback mechanism on the hypothalamic-pituitary axis to inhibit gonadotropin secretion. It has long been recognized that testosterone has an immune-modulating action. The greater incidence of immune-mediated disease in women and androgen-deficient men has been attributed to the immunosuppressive effects of androgens compared with estrogens (1). Laboratory studies using animals with experimental induced inflammatory disease have reported a beneficial response with androgens (2–4). Moreover, there are several case reports and small clinical trials of testosterone therapy in humans with rheumatoid arthritis and systemic lupus erythematosus in which major improvements of clinical status and inflammatory markers have been recorded (5–7). The mechanism by which testosterone affects these responses is uncertain, but laboratory evidence has suggested that testosterone suppresses proinflammatory cytokines and may up-regulate antiinflammatory cytokines. Despite the varied approach of these studies, the response to testosterone appears to be similar, so that testosterone incubated in cell culture attenuates the production of inflammatory cytokines such as TNFα, IL-1β, and IL-6 in human macrophages (8), human monocytes (9), human gingival fibroblasts (10), murine and human osteoblasts (11, 12), and human endothelial cells (13). Furthermore, antiinflammatory cytokines such as IL-10 are stimulated in the presence of testosterone (14, 15).

There have been few in vivo studies with highly varied experimental approaches. Injection of bacterial endotoxin into castrated male mice increased the endogenous production of TNFα, which was abrogated by testosterone replacement (16). Macrophages taken from castrated mice subjected to trauma hemorrhage had increased production of IL-1β and IL-6 compared with sham-castrated animals subject to the same procedure (17). In the few human studies, elderly men with hypogonadism induced with gonadotropin hormone-releasing agonists developed significant increases in serum TNFα and IL-6 (18). Although testosterone replacement reduced the levels of proinflammatory serum cytokines the reduction did not achieve statistical significance. A cohort of 29 hypogonadal young men with delayed puberty was found to have increased levels of immune activation compared with age-matched healthy controls. The immune activation was normalized with androgen-stimulating therapy (19).

There have been two prospective studies of androgen therapy in men with partial androgen deficiency, but neither showed any convincing effects on inflammatory cytokines.

Abbreviations: HDL, High-density lipoprotein; LDL, low-density lipoprotein; PSA, prostate-specific antigen.

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Ng et al. (20) used dihydrotestosterone, recombinant human chorionic gonadotropin, or a control in healthy men with total testosterone levels below 15 nmol/liter and found no changes in C-reactive protein or the soluble cellular adhesion molecules intracellular adhesion molecule-1 and vascular cell adhesion molecule-1. Lambert et al. (21) used megestrol acetate with testosterone injections, resistance training, or both in elderly eugonadal men, but no treatment effects on serum TNFα or leptin were found. To our knowledge there are no published data on the inflammatory/cytokine balance in postpubertal men with symptomatic androgen deficiency, nor is there any information on the effects of testosterone replacement on the cytokine balance in these hypogonadal men.

The aim/hypothesis of this study was to assess the effects of testosterone replacement on circulating inflammatory cytokines, antiinflammatory cytokines, and plasma lipids.

**Subjects and Methods**

This was a randomized, single-blind, placebo-controlled, crossover trial of testosterone replacement in hypogonadal men. The primary outcome was the serum level of TNFα. Eligible androgen-deficient men were recruited from a male andrology clinic before commencing testosterone replacement. Patients provided written informed consent and underwent a screening protocol before entry and randomization. Treatment began with either testosterone or placebo for 1 month, each comprising three injections given at 0, 14, and 28 d. Assessments were performed at baseline and on d 30 of each phase; thus, the follow-up assessments were performed 2 d after the final injection in each phase. There was 1 month of no treatment (washout) between the two treatment phases.

Subjects were referred back to the andrology clinic after completion of the trial protocol for continuing management and testosterone replacement. There were no changes to concomitant medications during the study period.

**Setting**

This study was performed at the andrology outpatient department, Royal Hallamshire Hospital; Sheffield Cardiology Research Department, Royal Hallamshire Hospital Sheffield; and Center for Diabetes and Endocrinology, Barnsley District General Hospital, Barnsley.

**Subjects**

Patients were males referred to the andrology clinic who were androgen deficient and for whom androgen replacement was deemed clinically indicated by a consultant endocrinologist (T.H.J.; Table 1). Twelve of the patients had primary gonadal failure with elevation of gonadotropins above the normal range; one of these patients had Noonan’s syndrome, and two had Klinefelter’s syndrome. Four patients had hypogonadotrophic hypogonadism with low gonadotropin levels; one of these had hemochromatosis, and the other three other had no underlying diagnosis, although pituitary magnetic resonance imaging was normal in each case. The remaining patients (n = 11) had a mixed picture of hypogonadism, with low serum testosterone levels and gonadotropin levels within the normal range. The local regional ethics committee approved the protocol, and patients provided written informed consent.

Inclusion criteria for trial patients were age greater than 18 yr with a clinical indication for testosterone replacement. Exclusion criteria were elevation of prostate-specific antigen (PSA) above the age-adjusted normal range, malignancy, and any acute or chronic inflammatory condition.

**Randomization, drug treatment, and blinding**

We used a standard regimen of testosterone therapy in hypogonadal men, which comprised fortnightly injections of depot testosterone. Testosterone (100 mg testosterone esters/ml; Sustanon 100, Organon, West Orange, NJ) or placebo (1 ml 0.9% normal saline) in an identical syringe was given by deep injection every fortnight by a member of the research staff (C.J.M. or P.J.P.) in the cardiology research department, with three injections given in each 1-month period. Subjects were blinded to the identity of the injection, and the drug was drawn up away from the patient. The order of drug administration was allocated using blocks of computer-generated numbers.

**Outcome measures**

The primary outcome was the serum level of TNFα. All assessments were performed in the cardiology research department.

**Drugs**

Calcium antagonist 16

ACE/ARB 10/1

Calcium antagonist 16

Mixed-dose 6

ACE/ARB 10/1

Diuretic 4

BMI, Body mass index; ACE, angiotensin converting enzyme inhibitor; ARB, angiotensin receptor blocker; HMG-CoA, 3-hydroxy-3-methyl-glutaryl-coenzyme A.

**TABLE 1. Baseline characteristics**

<table>
<thead>
<tr>
<th>Clinical characteristic/normal range</th>
<th>Patients (n = 27)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>61.6 ± 9.3</td>
<td>36–78</td>
</tr>
<tr>
<td>BMI (kg/m²) (20–25)</td>
<td>29.0 ± 6.9</td>
<td>21.5–57</td>
</tr>
<tr>
<td>Total testosterone (nmol/liter) (&gt;12 nmol/liter)</td>
<td>4.39 ± 1.24</td>
<td>0.9–17</td>
</tr>
<tr>
<td>Bioavailable testosterone (nmol/liter) (&gt;2.5 nmol/liter)</td>
<td>2.42 ± 1.07</td>
<td>0.2–6.4</td>
</tr>
<tr>
<td>FSH (IU/liter)</td>
<td>12.4 ± 10.5</td>
<td>1.9–46.8</td>
</tr>
<tr>
<td>LH (IU/liter)</td>
<td>8.6 ± 12</td>
<td>1.2–59.5</td>
</tr>
<tr>
<td>SHBG (nmol/liter)</td>
<td>16.9 ± 7.1</td>
<td>8.7–32.7</td>
</tr>
<tr>
<td>Total cholesterol (mmol/liter)</td>
<td>4.86 ± 1.1</td>
<td>3.3–7.6</td>
</tr>
<tr>
<td>TNFα (pg/ml)</td>
<td>5.78 ± 8.4</td>
<td>1.05–37</td>
</tr>
<tr>
<td>IL-1β (pg/ml)</td>
<td>0.41 ± 0.49</td>
<td>0.03–1.679</td>
</tr>
<tr>
<td>IL-6 (pg/ml)</td>
<td>4.7 ± 4.9</td>
<td>0.7–23.7</td>
</tr>
<tr>
<td>IL-10 (pg/ml)</td>
<td>3.3 ± 4.3</td>
<td>0.03–1.7</td>
</tr>
<tr>
<td>Androgen Deficiency Questionnaire Score (out of 10)</td>
<td>6.7 ± 2.3</td>
<td>4–10</td>
</tr>
</tbody>
</table>

**Concomitant disease (n)**

Chronic heart failure 2

Coronary heart disease 20

Previous myocardial infarction 9

Hypertension 10

Diabetes mellitus 9

Current smoker 4

Drugs (n)

Aspirin/ clopidogrel 19/1

HMG-CoA inhibitor 20

Oral nitrate 13

β-Blocker 12

Calcium antagonist 16

ACE/ARB 10/1

Diuretic 4

**B**MI, Body mass index; **ACE**, angiotensin converting enzyme inhibitor; **ARB**, angiotensin receptor blocker; **HMG-CoA**, 3-hydroxy-3-methyl-glutaryl-coenzyme A.

**Randomization, drug treatment, and blinding**

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one. SHBG-bound testosterone is then precipitated out of the sample by the addition of cold ammonium sulfate. The remaining [3H]testosterone, comprising the unbound fraction and the fraction weakly bound to albumin, is then measured with a β-counter. The intra-and interassay coefficients of variation of these assays were less than 5% and less than 6%; SHBG, less than 9% and less than 12%; and bioavailable testosterone, less than 5% and less than 8%. PSA, gonadotropins, and lipid profiles were measured with a standard hospital assay; low-density lipoprotein (LDL) cholesterol was calculated with the Friedwald equation LDL = total cholesterol − [high-density lipoprotein (HDL) + triglycerides/5]. Serum TNFα, IL-1β, and IL-6 were assayed with high sensitivity quantitative sandwich enzyme immunoassay (Quantikine, R&D Systems, Abingdon, UK). The minimum detectable level for TNFα is 0.12 pg/ml, and those for IL-1β and IL-6 are less than 0.1 pg/ml. The intra- and interassay coefficients of variation of these assays were less than 11.5% and less than 19.5%, respectively. Serum IL-10 was measured with high sensitivity quantitative sandwich assay; low-density lipoprotein (LDL) cholesterol was calculated with the Friedwald equation LDL = total cholesterol − HDL − Triglycerides/5. The intra- and interassay coefficients of variation were both less than 10%. Serum levels of proinflammatory cytokines should be undetectably low in 25% of young normal subjects.

**Statistical analysis and sample size determination**

There are no pilot data on which to base a sample size calculation. However, in a study of lipid-lowering therapy in hyperlipidemic patients, active treatment resulted in a reduction of circulating TNFα from 19.2 ± 5.1 to 9.2 pg/ml. To detect half this reduction in a placebo-controlled, crossover study with 95% power and 5% significance, it was estimated that 22 patients would be required. It was anticipated that drop-out rates would be low, and therefore, we planned to recruit 30 patients. All data are presented as the mean ± SD unless stated otherwise; analysis was performed with a statistical package (SPSS version 11.5, SPSS, Inc., Chicago, IL). Data were tested against a normal distribution using Kolmogorov-Smirnov tests. The serum levels of cytokines and most serum levels of cholesterol were nonparametric, so the Wilcoxon paired rank test was used throughout for paired data, and Mann-Whitney U tests were used for unpaired data. The correlation between data were examined using Spearman’s rank correlation (rS), and in all cases P < 0.05 was considered significant. Two subgroup analyses were performed, so a Bonferroni correction was made to calculate the final test statistic. Comparisons of baseline values and of treatment period interaction were performed with a t test.

**Results**

Twenty-nine patients agreed to take part in the study. Samples for one patient for one visit were lost, and one other patient was called for coronary artery bypass surgery sooner than expected and was withdrawn from the study. This provided data for 27 patients, but delta analysis could only be performed on 25 patients because a single visit set of sera for two patients was unsuitable for analysis. These results are summarized in Table 2. There were no time or period treatment effects of significance, and the baseline values for each cytokine and lipid fraction in the testosterone and placebo phases were not statistically different. Testosterone caused a reduction of the serum cytokins TNFα and IL-1β. By analysis of the delta values between testosterone and placebo, testosterone effected a reduction of TNFα (−3.1 ± 8.3 vs. 1.32 ± 5.2 pg/ml; P = 0.012) and an increase in IL-10 (0.33 ± 1.8 vs. −1.1 ± 3.0 pg/ml; P = 0.014). The reduction in IL-1β only approached significance (−0.14 ± 0.32 vs. 0.18 ± 0.55 pg/ml; P = 0.08; Fig. 1). The reduction of TNFα and IL-1β was positively correlated (rS = 0.588; P = 0.003; Fig. 2).

Two of the hypogonadal patients had very high basal TNFα levels. A subgroup analysis was performed on the study group with these two patients removed, and the reduction in TNFα with testosterone by analysis of the delta remained significant (−0.72 ± 1.7 vs. 0.34 ± 1.6 pg/ml; P = 0.04, corrected).

A subgroup analysis of the response of TNFα in the 20 patients with coronary disease was also performed. The effect remained highly significant; the difference by delta analysis for testosterone was −4.1 ± 9.1 vs. 1.5 ± 5.9 pg/ml for placebo (P = 0.016, corrected).

The testosterone phase of treatment was also associated with a reduction of total cholesterol and serum triglycerides (Table 2), although by analysis of the delta values, only the reduction in total cholesterol remained significant (Fig. 3). The reduction of LDL cholesterol with testosterone was not significant (−0.11 ± 0.5 vs. 0.14 ± 0.98 mmol/liter; P = 0.3), but the reductions in total cholesterol and LDL cholesterol were positively correlated (rS = 0.531; P = 0.005), suggesting a relationship (Fig. 4).

There were no significant effects on HDL cholesterol (−0.02 ± 0.12 vs. −0.05 ± 0.21; P = 0.84).

**Discussion**

This study found that 1 month of testosterone replacement given to men with symptomatic androgen deficiency resulted in statistically significant reductions of TNFα and IL-1β compared with placebo, and there was a statistically significant increase in IL-10 by delta analysis. The baseline TNFα was higher in the testosterone phase, but not significantly so. There were no treatment/period effect of significance. Two of the hypogonadal patients had very high basal TNFα levels; both of these men had mild chronic congestive heart disease.
heart failure, a condition characterized by high basal TNFα values. A subgroup analysis was performed on the study group with these two patients removed, but the reduction in TNFα with testosterone by analysis of the delta remained significant. The TNFα response to testosterone of these patients was very sensitive, and both demonstrated large reductions compared with the effect of placebo. This is an intriguing finding, because the progression and prognosis of heart failure are linked to catabolic compounds such as TNFα, and there have been a number of attempts to reduce TNFα pharmacologically as a treatment for heart failure (23), although with limited clinical benefit (24). Preliminary data suggesting reductions of TNFα in heart failure patients with testosterone therapy should provoke interest in further studies in this group.

The largest comorbid group was patients with coronary disease (n = 20); this included the two patients with congestive heart failure. Atherosclerosis is acknowledged to be a disease of chronic inflammation, and inflammatory cytokines such as TNFα and IL-1β are mediators of atherosomatous plaque development and complications (25). Antiinflammatory cytokines such as IL-10 can regulate inflammation and may inhibit atherosclerosis (26, 27), and elevation of IL-10 after an acute coronary syndrome confers a favorable prognosis (28). Subgroup analyses in patients with coronary disease (n = 20) substantially weakened the results, with only TNFα retaining statistical significance. This analysis suggests that testosterone had an antiinflammatory effect in all patients, not just in a subgroup with established vascular disease.

The use of 3-hydroxy-3-methyl-glutaryl-coenzyme A enzyme inhibitors was high (n = 20). The reason for statin therapy was secondary prevention for vascular disease in most cases. Despite the presence of vascular disease, the dyslipidemia in these patients may reflect the underlying androgen status, because there are reports of dyslipidemia associated with hypogonadism (29, 30). However, the raised body mass index and high prevalence of type 2 diabetes (n = 9) are also likely to contribute. Testosterone replacement caused a significant reduction in total cholesterol and triglycerides, although by delta analysis only the reduction of total cholesterol remained significant. In general, our results agree with most studies of the effect of androgen replacement in cholesterol profiles, with modest reductions of total cholesterol and LDL cholesterol reported by a recent meta-analysis (31). We did not find a reduction in HDL cholesterol in our study that was documented in the meta-analysis performed by Whitsel et al. (31). This effect of testosterone on
HDL cholesterol is reported to be reduced or absent in hypogonadal or obese men (32, 33), and in our study may also be masked by the positive effects of testosterone on insulin resistance that have been reported in obese men (34) and in asymptomatic men with low serum testosterone levels (35).

We have shown that testosterone replacement induces an antiinflammatory shift in cytokine balance. This study is one of the very few in vivo studies and the only in postpubertal men with idiopathic disease to demonstrate a convincing antiinflammatory effect of testosterone. Moreover, the observed effect has a potentially beneficial action in men with coronary disease due to atherosclerosis. An anticytokine effect in this inflammatory condition may positively affect plaque biology and stability.

The observed reduction in total cholesterol may be related to the reductions in inflammatory cytokines, as cholesterol reduction with statins is itself associated with an anticytokine effect (36, 37). However the reduction of TNFα and IL-1β did not correlate with the reduction in total cholesterol or LDL cholesterol, suggesting the lack of a relationship. Furthermore, we cannot exclude an interaction between statin therapy and testosterone, because postmenopausal women treated with hormone replacement and statins have greater reductions in total cholesterol than those given statins alone (38, 39).

Conclusions

Testosterone replacement in men with symptomatic androgen deficiency is indicated to improve quality of life, maintain lean body mass, and preserve bone density. Although this trial enrolled a mixed population of hypogonadal or obese men (32, 33), and in our study may also be masked by the positive effects of testosterone on insulin resistance that have been reported in obese men (34) and in asymptomatic men with low serum testosterone levels (35). We have shown that testosterone replacement induces an antiinflammatory shift in cytokine balance. This study is one of the very few in vivo studies and the only in postpubertal men with idiopathic disease to demonstrate a convincing antiinflammatory effect of testosterone. Moreover, the observed effect has a potentially beneficial action in men with coronary disease due to atherosclerosis. An anticytokine effect in this inflammatory condition may positively affect plaque biology and stability.

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